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AUTHORITY

SAMSO ltr, 16 Aug 1973

AEROSPACE REPORT NO.
TOR-0158(3107-20)-1

MOL Safety Evaluation

Based on Apollo 204 Review Board Findings and Recommendations and Brooks Air Force Base Accident Investigation Board Conclusions

SEPTEMBER 1967

Prepared by MOL SYSTEMS ENGINEERING OFFICE
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Prepared for DEPUTY DIRECTOR
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CONTRACT NO. F04695-67 C-0158

AEROSPACE CORPORATION

58

AD856687

Report No. TOR-0158(3107-20)-1

MOL SAFETY EVALUATION BASED ON APOLLO 204 REVIEW BOARD FINDINGS AND RECOMMENDATIONS and BROOKS AIR FORCE BASE ACCIDENT INVESTIGATION BOARD CONCLUSIONS

Prepared By:

MOL Systems Engineering Office
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Contract No. F04695-67-C-0158

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MOL SAFETY EVALUATION

Prepared by

MOL Systems Engineering Office

Approved by

J. R. Henry
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Safety Office
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FOREWORD

The Vice Director, MOL Program, requested a narrative report evaluating the MOL Program with respect to each Apollo 204 Review Board finding and recommendation and the conclusions of the Brooks Air Force Base Accident Investigation Board. This report was prepared at the request of the MOL SPO as the initial step ~~in~~ fulfilling that requirement. This is a status report only since the total evaluation and MOL reactions are not yet complete.

CONTENTS

CONTENTS (Continued)

FIGURES

TABLES

1. INTRODUCTION

The purpose of this report is to summarize the MOL Program activities in light of the findings and recommendations of the Apollo 204 Review Board and the conclusions of the Brooks Air Force Base Accident Investigation Board. The MOL baseline design and planning were reviewed in depth, and it was found that, in general, the MOL baseline design includes nearly all the elements required for safety; however, several areas have been identified for further improvement, and these are described in this report.

The safety evaluation of the MOL Program is continuing. This report is, therefore, a status report since many of the studies, analyses, and reexaminations necessary to define MOL courses of action are not yet complete. The impact on the MOL Program will be determined later in 1967, although changes, modifications, or similar actions which appear meritorious will be introduced in the program as they arise.

1.1 GENERAL DESCRIPTION, MOL ORBITING VEHICLE

The Orbiting Vehicle (Figure 1-1) consists of the Gemini B and the Laboratory Vehicle, is launched by Titan IIIM, and placed into Earth orbit. After successful orbit has been established, the flight crew transfers from the Gemini B to the Laboratory Vehicle via the internal tunnel. When the on-orbit mission has been completed, the crew transfers back to the Gemini B. When transfer is completed, the Gemini B separates from the Laboratory Vehicle and returns to Earth. Re-entry and recovery sequences are similar to those employed on the NASA Gemini Program.

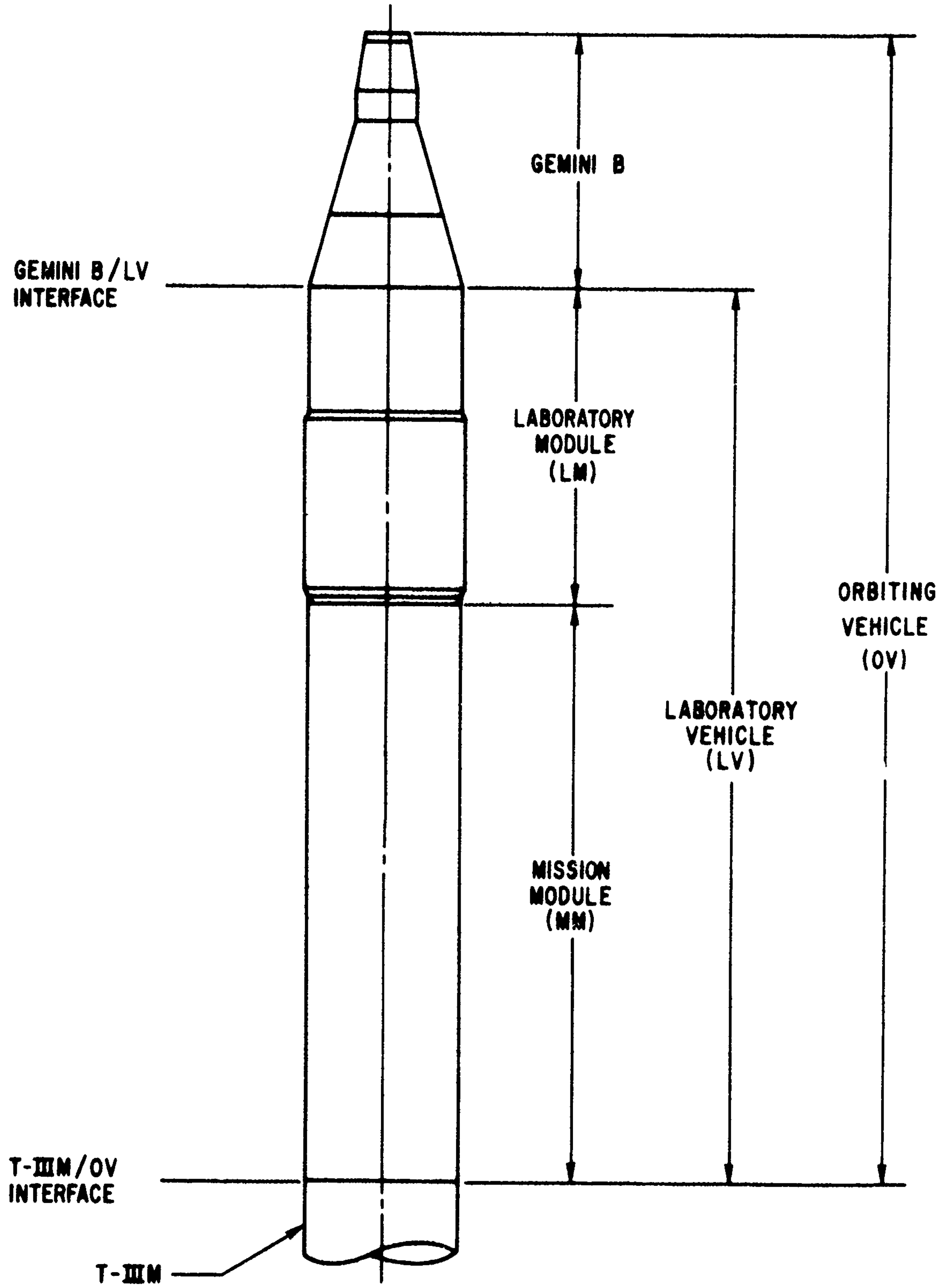


Figure 1-1. Orbiting Vehicle Configuration

The Gemini B vehicle is essentially the same configuration as the NASA Gemini spacecraft except for a newly designed adapter. The most significant change is the construction of an access hatch in the heat shield which provides entrance to the transfer tunnel in the adapter.

Certain Gemini design features result in enhancing the fire safety: (1) the bulk of the electronic equipment is in the unpressurized compartments, (2) the crew egress hatches can be opened in less than 10 seconds by either the flight crew or ground crew and (3) the egress hatches when opened expose a substantial portion of the pressure cabin for emergency access. The original Gemini B design had a pure oxygen atmosphere with approximately the same pressure history as Apollo 204. This has now been changed to the two-gas system more fully explained in Section 2.

The Laboratory Vehicle consists of the Laboratory Module and the Mission Module. The Laboratory Module is 19 ft long with one unpressurized compartment for storage and one pressurized compartment where the two-man crew lives and works in a shirt sleeve environment. Double-walled structure provides environmental, radiation, and meteoroid protection. The Mission Module is 37 ft long and holds equipment for experiments which vary with the mission. There is no crew access to the Mission Module.

The Laboratory Vehicle baseline design contains many features that enhance fire safety. These include: (1) a two-gas (oxygen-helium) atmosphere, (2) emergency face masks with independent oxygen supply, (3) a coolant system that utilizes water as a coolant fluid in the cabin and freon outside the cabin, and (4) the capability to transfer rapidly from the Laboratory to the Gemini in an emergency.

2. GENERAL

MOL safety activities did not start with the Apollo accident; rather, considerable analyses had already been performed and planning completed prior to that time. MOL had the advantage of entering its design phase after Apollo, and it was possible to draw on NASA experience to influence the initial MOL design at the outset, in the direction of improved safety. These activities are briefly summarized in Section 2.1.

Section 2.2 is a comparison of MOL with Apollo 204 Review Board findings and recommendations. Section 2.3 is a similar review of the conclusions of the Brooks AFB Accident Investigation Board.

2.1 BACKGROUND ON MOL SAFETY

Throughout the conceptual, definition, and engineering phases of the MOL Program, the safety aspects of manned space flight and associated manned development testing have been, and continue to be, of major concern. At the system, segment, and subsystem levels, all analyses with respect to configuration, design, redundancy, maintainability, launch operations, flight operations, and testing have considered the safety aspects of alternative approaches as a significant factor in the definition of the baseline system.

With the program proceeding into the Engineering Development Phase, continuing emphasis has been placed on safety aspects by means of specified safety activities in the negotiated contracts and limits on failure rates and crew fatality rates in the MOL System Performance/Design Requirements Specification (Reference 5) and Contractor End Item Specifications. These include the applicability of MIL-S-38130, General Specification for System Safety Engineering of Systems and Associated Subsystems and Equipment, (Reference 1) to contractor activities, as well as requirements for contractor establishment of safety organizations, preparation of safety plans, participation in safety working groups, conduct of safety analyses and corrective

actions, safety support of design activities, safety review of test plans and procedures, safety inspections, and safety probability studies as a part of system effectiveness analysis.

Safety analysis and tradeoff studies will be continued to a level of detail considerably beyond those analyses undertaken during the program definition period and for all phases of the MOL mission. The enlarged scope now becomes practical as the detailed engineering design of the system is defined in greater depth. Formal working groups to direct Associate Contractor and in-house efforts in this area have been established, permitting SPO/Aerospace to effectively integrate multi-segment safety activities in a manner consistent with the retention of a reasonable balance between safety, weight, costs, complexity, etc.

As an example of the type of activity discussed in the preceding paragraphs, the relatively advanced state of definition of the Gemini B and Titan IIIM segments of the overall flight vehicle permitted the functioning of an Ascent Crew Safety Working Group for over two years. The basic problem confronting this group was to marry two existing vehicles (the manned spacecraft and the launch vehicle) that were not designed to the same safety and abort requirements. In analyzing the crew safety problem for the ascent phase of the mission, a basic three-step approach was adopted. First, basic design criteria were established and ground rules for the analytical effort formulated. Next, gross subsystem tradeoff studies were initiated to establish an overall flight configuration meeting the established design criteria including consideration of redundancy requirements, escape systems, and escape procedures. For example, various abort systems such as an escape tower, increased adapter propulsion, and uprated ejection seats were compared in various combinations for effectiveness in reducing crew fatalities and improving mission success as well as program cost, vehicle weight, and impact on vehicle design. As a result of these analyses, redundant guidance and control systems for the booster and additional propulsion capability in the

Gemini B adapter (also required for the near-polar orbit re-entry) were delineated as system requirements. Detailed analyses were then performed including failure modes and effects on the booster and Gemini B leading to the specification of an improved malfunction detection system for the booster, a blast shield between the Gemini B and Laboratory Vehicle, and an additional simplified reaction control system on the Gemini B to overcome aerodynamic instability during a pad abort. These analyses will continue until there is a design freeze on the malfunction detection system hardware; future emphasis will be concerned with the detailed definition of crew procedures in emergency situations.

While appropriate safety analyses and activities have always been an integral part of the MOL development program, a critical review of MOL following the Apollo 204 accident resulted in a clearer understanding of realistic safety problems and the surfacing of areas requiring improvement. This review resulted in an acceleration of many of these safety efforts, with particular emphasis being given to those aspects of the overall safety problem related to potential fire hazards. The major contribution to MOL safety resulting from this accelerated review is an increased emphasis on safety and a stronger safety organization.

The MOL SPO and Aerospace have closely followed the activities of the Apollo Review Board. The SPO was continuously supplied information during the period the Board operated. A MOL SPO representative participated in the 204 investigation in a liaison capacity and kept the MOL SPO and Aerospace informed of all developments. In addition, a number of safety meetings have been held between NASA-MSC, MOL SPO, Aerospace Corporation and the MOL Associate Contractors which have resulted in a valuable exchange of information.

There have been similar technical interchanges with the Air Force Aerospace Medical Division concerning its activities following the Brooks AFB fire.

2.2 COMPARISON OF MOL WITH APOLLO 204 BOARD FINDINGS, DETERMINATIONS AND RECOMMENDATIONS

The results of the Apollo 204 Review Board findings and recommendations are given in Reference 4. For convenience, these are summarized in Appendix I.

At stated in Section 2.1, the MOL Program had either already included requirements similar to the board recommendations or has initiated efforts to evaluate their impact on the MOL Program. In the following paragraphs, each Apollo Board recommendation is listed and the applicable MOL activities are discussed for comparison. This comparison is summarized in Table 2-1.

2.2.1 Board Recommendation No. 2

The amount and location of combustible materials in the Command Module must be severely restricted and controlled.

Implementation of this recommendation will result in a considerable impact on MOL because every subsystem will require detailed review and evaluation. Many components may require change. Control of materials will require major effort on the part of both the Associate Contractors and SPO/Aerospace.

Prior to the Apollo accident, the MOL Program implemented some requirements for selection and control of nonmetallic materials through a series of contractual exhibits for the Laboratory Vehicle and Mission Payload Contractors. These exhibits were to some extent based upon NASA data prior to the Apollo fire. The Gemini B had no specific requirement since the materials used were based on NASA Gemini, and no reason requiring change was evident before the Apollo accident.

Table 2-1. Comparison of Apollo 204 Review Board Recommendations and MOL Program Activities

BOARD FINDING NO.	BOARD RECOMMENDATION Appendix I	MOL ACTIVITY
2	The amount and location of combustible materials in the Command Module must be severely restricted and controlled.	MOL has established a materials combustion and control specification which will become a contract requirement.
4	The time required for egress of the crew to be reduced and the operations necessary for egress to be simplified.	Current egress capability is superior to Apollo 204. However, improvements in both spacecraft egress time and facilities support are being developed.
5	a. Management to continually monitor the safety of all test operations and assure the adequacy of of emergency procedures. b. All emergency equipment to be reviewed for adequacy. c. Personnel training and practice for emergency procedures to be given on a regular basis and reviewed prior to conduct of a hazardous operation.	The MOL launch operations contracts, not yet negotiated, will involve these requirements in the specifications and statements of work to be negotiated approximately January 1968.
	d. Service structures and umbilical towers be modified to facilitate emergency operations.	The MOL Launch Complex design was re-examined and was found to include most of the required features. Further improvements are being made. Certain areas, such as crew egress provisions and fire suppression within the environmental enclosure external to the vehicle are undergoing further study.
6	a. The ground communication system to be improved to assure reliable communications between all test elements as soon as possible and before the next manned flight.	The MOL ground communication system design is being reviewed as it is developed. Proper discipline in the use of the system will be implemented when detail test procedures are prepared. Equipment and procedural improvements are being incorporated as the design progresses.
	b. A detailed design review to be conducted on the entire spacecraft communication system.	Gemini B system is essentially same as NASA Gemini System has had Preliminary Design Review with detailed review scheduled for late 1967 during which safety aspects will receive critical attention.
7	a. Test procedures and pilot's checklists that represent the actual Command Module Configuration to be published in final form and reviewed early enough to permit adequate preparation and participation of all test organizations. b. Timely distribution of test procedures and major changes be made a constraint to the beginning of any test.	See MOL activity under Finding No. 5. MOL segment and integrated checkout requirement plans due 12 months before launch, with test procedures due 30 days before use. (1) Procedures subject to review of 6595th ATW and SPO/Aerospace Safety teams. (2) Major revisions will be approved only after carefully examining impact. (3) Procedure documents will include both normal and emergency procedures.
8	Full-scale mockups in flight configuration to be tested to determine the risk of fire.	MOL is evaluating use of boilerplates and mockups for testing. Principle benefit appears to be evaluating hazard from use of restricted usage materials. However, where significant and useful tests can be made, they will be introduced.

Table 2-1. Comparison of Apollo 204 Review Board Recommendations and MOL Program Activities (Continued)

BOARD FINDING NO.	BOARD RECOMMENDATION Appendix I	MOL ACTIVITY
9	a. The fire safety of the reconfigured Command Module to be established by fullscale mockup tests.	See MOL activity under Finding No. 8.
	b. Studies of the use of a diluent gas to be continued with particular reference to assessing the problems of gas detection and control and the risk of additional operations that would be required in the use of a two-gas atmosphere.	MOL will eliminate all manned operations in partial pressures of oxygen greater than 6 psi. This requires changing Gemini B launch atmosphere to two-gas, and modifying the Laboratory launch atmosphere. Means to implement these have been evaluated and are being incorporated.
10	a. An indepth review of all elements, components, and assemblies of the environmental control system to be conducted to assure its functional and structural integrity and to minimize its contribution to fire risk.	Gemini B design was re-examined and found to include potential hazard due to use of aluminum coolant tubes containing flammable coolant. Remedial means are under study. The Laboratory design was found to be satisfactory.
	b. Present design of soldered joints in plumbing to be modified to increase integrity or the joints to be replaced with a more structurally reliable configuration.	Both the Gemini and Laboratory ECS utilize brazed or mechanical joints which are more structurally reliable than soldered joints.
	c. Deleterious effects of coolant leakage and spillage to be eliminated.	The Laboratory system uses water for the coolant fluid in the pressure compartment minimizing hazards due to spillage and leakage. The Gemini uses a flammable fluid as discussed in a. above. Alternative less flammable coolant fluids are being evaluated.
	d. Review of specifications be conducted, three-dimensional jigs to be used in manufacturing wire bundles. Rigid inspection of all stages of wiring design, manufacture, and installation to be enforced.	MOL has instituted a detail review of all contractor's specifications, procedures, etc. This activity is currently in process, and will continue to ensure enforcement of wiring design, fabrication and installation requirements. Three-dimensional jigs will be used where required to properly manufacture wire bundles
	e. Vibration tests to be conducted of a flight-configured spacecraft.	Vibration tests for both the Gemini B and Laboratory Vehicle in a flight configuration are baseline.
	f The necessity for electrical connections and disconnections with power on within the crew compartment to be eliminated	The MOL system is currently being reviewed for equipment that is to be disconnected/connected with power on. The crew transfer umbilical has been identified to date.
	g. Investigation to be made of the most effective means of controlling and extinguishing a spacecraft fire. Auxiliary breathing oxygen and crew protection from smoke and toxic fumes to be provided.	MOL is evaluating fire detection and suppression systems for use in the Gemini, the Laboratory, and the test facilities. Oxygen masks with independent oxygen supply are baseline for the MOL.
11	Every effort must be made to insure the maximum clarification and understanding of the responsibilities of all organizations involved, the objective being a fully coordinated and efficient program.	MOL is re-examining the overall safety planning. A MOL safety plan is in preparation to set overall requirements, identify organization responsibilities, and identify lower tier documentation to provide a means for surveillance of all safety regulated MOL activities.

Subsequent to the Apollo fire, the MOL Program Office initiated a review of available data, mostly from NASA sources, which included Apollo Board findings. This review culminated in the preparation of a proposed contract exhibit which is addressed to material combustion and atmospheric contaminant requirements and control. The draft exhibit has been circulated among the Associate Contractors for comments. It will be published in final form by early Fall and made contractually binding.

The criteria for acceptance of materials (relative to the fire and toxicity hazards) are delineated in nine categories based on functional application and/or location in the Orbiting Vehicle. The requirements for each category are specified in terms of the most severe environment in which the material will be used. If a material satisfies the more stringent requirements, it may be applied to components that have less severe requirements without further testing.

The categories are as follows:

Category A - Unrestricted-Usage Materials

Category B - Materials in the Gemini B Pressurized Area, Tunnel Area, and Laboratory-Module Pressurized Compartment

Category C - Suit-Loop Materials

Category D - Materials in High-Pressure Oxygen Systems

Category E - Materials in Hermetically Sealed Containers

Category F - Materials in Vented Containers

Category G - Non-Flight Materials

Category H - Materials in Unmanned Areas

Category I - Electrical Wiring and Accessory Materials

These categories correspond with those developed by NASA (Reference 2) with the exception that Category I - Electrical Wiring and Accessory Materials, has been added. This was done because electrical power systems present a major potential ignition source and should be given special attention. For

convenience, Table 2-2 is a matrix summarizing the criteria for each category. Certain screening tests are repeated in various categories, Table 2-3 presents these requirements in the most convenient fashion.

A nonmetallic materials control plan is also being implemented through this contractual exhibit which requires that all MOL contractors prepare and implement a nonmetallic materials control plan to accomplish the following:

(a) Establish a Nonmetallic Materials Review Board to review, approve, or reject proposed deviations to the contractual exhibit. The board will report its findings and recommendations to the MOL SPO for final approval.

(b) Establish a Nonmetallic Materials Control Desk.

(c) Account for materials usage according to the categories as required in the contractual exhibit.

(d) Account for and define all support equipment and materials used to install, modify, check out, and validate elements in the orbiting vehicle.

(e) Control materials substitution and deviations.

(f) Provide for batch control to insure that material properties have not varied in such a way that flammability and toxicity characteristics will invalidate prior acceptance of the material.

Special action was necessary in the case of electrical wire. since procurement lead time for special wire is from two to nine months and program schedules dictated that wire be immediately procured for the program. In addition to consideration of such things as insulation ignition temperature, flame propagation rate, toxicity products, etc., it was equally important that manufacturing problems, such as availability of accessories, insulation cold flow, abrasion resistancy, etc. receive appropriate consideration.

Each Associate Contractor was directed to study the wire problem and to present study results to the SPO. Several potentially useful wire types were identified, and their advantages and disadvantages were considered. A

Table 2-2. Summary of Materials Acceptance Criteria

	CATEGORY								
	A	B	C	D	E	F	G	H	I
Melting Point, °F	>800°F	----	----	----	----	----	----	----	----
Combustion Rate, in. /sec	NI (6 psia) upward	<0.3 (6 psia) down-ward	SE (19 psia) upward	SE (19 psia) down-ward	----	----	SE upward in appl test env't	SE (air)	SE upward (air, 6 psia, or 19 psia as appl)
Outgassing Tests	NR	Yes	Yes	Yes	----	Yes (pres-surized areas only)	NR	NR	Yes (pres-surized areas only)
Flash and Fire Points, °F	>600°F (6 psia)	>500°F (6 psia)	>500°F (19 psia)	>500°F (19 psia)	----	>500°F (air or 6 psia as appl)	>500°F in appl test env't	>500°F (air)	NR
Elect'l Wire Accessory Flam. Test	----	----	----	----	----	----	----	----	Yes
Elect'l Connector, Potting/Coatings Flammability Test	----	----	----	----	----	----	----	----	Yes
Elect'l Harness Ass'y Overload Test	----	----	----	----	----	----	----	----	Yes
Special Test	----	Yes	----	Qual Test if nec.	Yes	Yes	----	----	----

NOTE: Pressures (psia) refer to oxygen.
NI = Non-Igniting
SE = Self-Extinguishing
NR = Test Not Required

Table 2-3. Screening Test Requirements

	Air	Test Environments: 6 psia O_2*	Test Environments: 19 psia O_2*
Combustion Rate, in. /sec. **	SE, upward	<0.3, downward	SE, upward
Flash and Fire Points	>500°F	>500°F	>500°F
Outgassing			
Odor Rating	NR	2.0 max. (average score)	
CO μg/g of sample	NR	5.0 max.	
Total organics, *** μg/g of sample	NR	111 as methane, max. 102 as propane, max. 100 as pentane, max.	

NOTES: SE = Self-Extinguishing
NR = Test Not Required

* These pressures apply to Combustion Rate and Flash and Fire Point tests, only. For outgassing measurements, 5 psia oxygen (260 ±5 Torr) is used.

** There shall be no ejection or drip of flaming particles from the specimen during this test.

*** Any outgassing product at a concentration of more than 20μg/g shall be identified.

SPO/Aerospace/Associate Contractor team visited wire manufacturers and users to get complete data prior to final wire selection.

The SPO has selected MIL-W-81381 Kapton as the wire insulation that best meets the overall requirements for wire harnesses. It satisfies the flammability and toxicity requirements of the exhibit and is relatively lightweight.

2.2.2 Board Recommendation No. 4

The time required for egress of the crew to be reduced and the operations necessary for egress to be simplified.

In general, the egress capability from the Gemini B on the pad while the Mobile Service Tower is in place is vastly superior to that of the Apollo 204 Command Module. The current baseline re-entry module permits opening the egress hatches (in 5 to 10 seconds) and completion of egress of both crewmen to the Mobile Service Tower platform in 15 to 21 seconds. The comparative timeline for Apollo 204 hatch opening is reported to have been 90 seconds. The design requirement for hatch opening time of the revised Apollo hatch is 2 to 4 seconds.

Experience gained during the NASA Gemini Program shows that the present Gemini configuration and procedures permit relatively fast egress during emergency conditions. Also, the hatches are large in comparison to the cabin size; this permits easy access to the crew and facilitates ground crew fire fighting. However, a re-evaluation of the Gemini B baseline was performed, including: (1) cabin egress equipment/capabilities and operational procedures for rapid egress under emergency pad conditions; and (2) applicable AGE, its availability time until actual launch, and potential modifications for more rapid egress.

Gemini B egress capability and procedures are dependent upon the countdown time at which an emergency might occur. The 120 minute period from crew

insertion to launch has been divided into two intervals for analysis. The first interval, approximately 30 minutes in length, is between crew insertion and start of preparation for removal of MOL Environmental Shelter. Both crewmen can egress from the Gemini B cabin directly onto the Mobile Service Tower or Umbilical Tower. Continuous external assistance from ground personnel is available during this interval. Emergency lighting and extra cranks for opening spacecraft hatches are also available on the service tower level within the shelter.

During this interval it takes approximately 21 seconds to egress from the spacecraft without outside aid (9 seconds to open the hatches and 12 seconds to release from the seats and to step onto the platform). This time has been verified through demonstrations by McDonnell crewmen using the Gemini B Engineering Compatibility Vehicle. With outside aid, egress time can be reduced to 15 seconds (5 seconds to open the hatches and 10 seconds to release from the seats and to step onto the platform). The 5 seconds has also been verified by demonstration, but the remaining 10 seconds is an estimate which will be demonstrated at a later date.

The second interval, lasting approximately 90 minutes, is between the start of preparation for shelter removal and launch. During this time, with the present design, there is a period of 3 minutes during which both crewmen must egress through the same hatch (the hatch closest to the Umbilical Tower). During the demonstration cited above, a total of 35 seconds were required for crew egress under this situation. There is also a period of 2 minutes during which both crewmen are denied any means of egress. These limitations on egress capability occur between the start of platform folding and completion of retractable and auxiliary platform positioning.

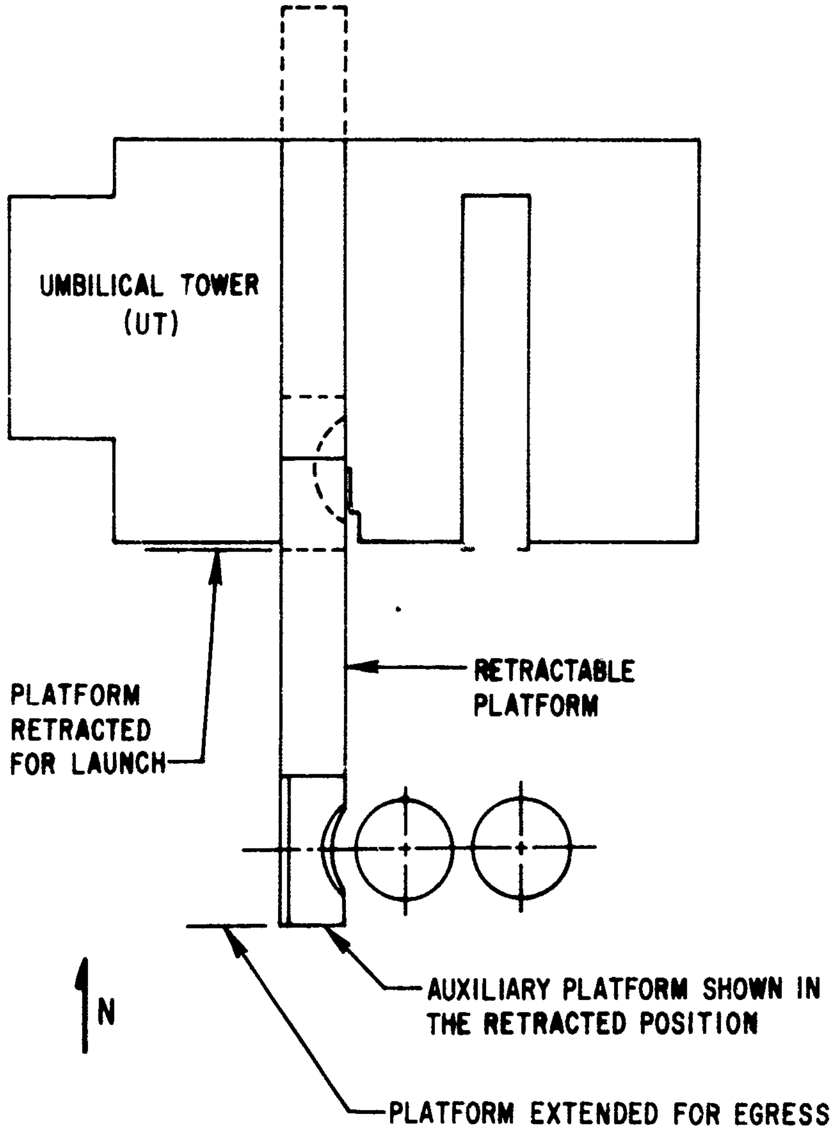
The present configuration of the Mobile Service Tower and the Umbilical Tower provides a crew egress path by means of a retractable and an auxiliary platform on Level 15 of the umbilical tower when the service tower is in the parked position, Figure 2-1. The auxiliary platform extends from the retractable platform in an easterly direction and closes the gap between the Gemini B and the extended retractable platform.

With the present configuration, the retractable and auxiliary platforms are retracted from the Gemini B approximately 3 minutes prior to launch. A method of crew escape from a pad emergency situation is then available by salvo firing the retrorockets and subsequent seat ejection (this takes from 1 to 5 seconds for escape).

A directive has been issued to the architectural engineering firm responsible for the facility design to recommend solutions to those facility limitations on egress and abort mentioned above. Program decisions will be based on these studies and practical corrections will be made.

Several methods to further improve crew egress from the reentry module under emergency conditions have been evaluated. These include the use of automatic rapid opening hatches, rapid hatch unlatching, and pyrotechnic release of the backboard. The use of quick opening hatches reduces the opening from 9 seconds to 0.5 seconds. With the present design, if either crewman pulls the ejection "D" ring of his ejection seat, both hatch actuators are fired which opens the hatches and vents gas (at the end of their strokes) to fire the ejection seat catapults. This results in the ejection of both seats from the spacecraft. Several methods of rapidly opening the hatch by the crew without firing the catapults were investigated.

Further evaluation of crew egress times using the existing hatch system will be made before it can be positively determined that any modification to the hatch opening system is required. If it is required, a method which eliminates the most complex part of the hatch opening cycle, (the unlatching operation)



72-in. RADIUS FROM VEHICLE ℄ FOR PAD ABORT (27 in. CLEARANCE)
52.5 in. RADIUS FROM VEHICLE ℄ FOR NOMINAL POSITION (7.5 in. CLEARANCE)
4-6 sec REACTION TIME FOR AUXILIARY PLATFORM EXTENSION

Figure 2-1. Modified Retractable and Auxiliary Platform

but does not change the existing seat ejection system or create additional hazard for ground personnel will be utilized.

The operational timelines are being examined to permit ground crew personnel to remain on the umbilical tower as late as possible during launch countdown. The present timeline calls for complete pad evacuation at T-30 minutes. Presence of ground crew personnel to assist the flight crewman shortens the exit time for the crewman from the Gemini.

After environmental shelter breakup and service tower retraction, three modes of egress from Umbilical Tower Level 15 to the ground are:

(a) two slide wires
(b) elevator
(c) stairs

The quickest means of descent from Level 15 is by slide wires; this requires approximately 40 seconds. The next fastest method is the elevator, which is now designed for a maximum speed to 150 feet per minute. It is estimated that descent via the elevator and travel to a ground point 1000 feet from the base of the umbilical tower would take 3 minutes and 20 seconds. Means of increasing the descent speed of the elevator are being investigated.

2.2.3 Board Recommendation No. 5

A. Management to continually monitor the safety of all test operations and assure the adequacy of emergency procedures.

B. All emergency equipment to be reviewed for adequacy.

C. Personnel training and practice for emergency procedures to be given on a regular basis and review prior to conduct of a hazardous operation.

D. Service structures and umbilical towers be modified to facilitate emergency operations.

Since the MOL launch support contracts with the Associate Contractors are not yet negotiated, the bulk of test operations are still in the planning stage. As a result of the Apollo Board findings, the requirements documents for MOL launch support are being reexamined for completeness and improved where they appear to be lacking. In the current baseline, the Contractor safety policies, constraints and criteria will be integrated into a MOL safety plan by an Air Force/Aerospace/Contractor working group for approval by the Deputy Director, MOL and the WTR Chief of Range Safety. This will be published at least nine months prior to first launch.

The planning for use of the Douglas Aircraft Company and McDonnell Company space simulation test chambers which will test major prime hardware used in MOL, was reviewed in detail for safety design features and procedures. These were found to be acceptable with only minor changes required. The Douglas chamber is in the process of being "manrated". These activities will be closely monitored by the SPO/Aerospace to ensure that planned safeguards are properly implemented.

The MOL SPO will institute a formal, senior-level management review and inspection of all test facilities and procedures prior to conduct of hazardous

tests, manned or unmanned. This will include tests in both Contractor and government facilities. All activities which have safety implications will be periodically reviewed by the MOL System Safety Group.

The MOL Launch Complex design was reviewed for adequacy relative to safety. Two areas were identified as requiring further investigation; flight crew egress capability (discussed in Paragraph 2.2.2) and fire detection and suppression within the Mobile Service Tower together with the MOL Environmental Shelter. The rest of the design is considered adequate; however, close surveillance will be employed to assure proper implementation of the proposed safety features.

2.2.4 Board Recommendation No. 6

A. The ground communication system to be improved to assure reliable communications between all test elements as soon as possible and before the next manned flight.

B. A detailed design review to be conducted on the entire spacecraft communication system.

The requirements for the MOL ground communication system are presently being established. A Ground Communications Plan which will reflect Apollo experience will be published in the Fall of 1967. Hazardous tests will not be started or continued if communications are faulty. Discipline in the use of the ground communication system, e.g., a minimum number of people will use the critical crew/launch control center communication link to assure that critical communications are maintained.

The Gemini B voice communication system is essentially the same as the NASA Gemini system. Both the airborne vehicle and ground equipment portions of this system have recently been subjected to a detailed design review. It should be noted that the Gemini has the capability for operating with either "voice operated" or "push-to-talk" microphones which was one of the Board recommendations for Apollo.

2.2.5 Board Recommendation No. 7

A. Test procedures and pilot's checklists that represent the actual Command Module configuration to be published in final form and reviewed early enough to permit adequate preparation and participation of all test organizations.

B. Timely distribution of test procedures and major changes to be made a constraint to the beginning of any test.

The Contractor checkout procedures, which are part of the work tasks scheduled for early negotiation, will include both normal and emergency procedures for each test activity. The segment and integrated checkout requirements plans will be due no later than 12 months before launch. Detailed test procedures will be available no later than 30 days prior to their scheduled use. These procedures will be reviewed and approved by the 6595th ATW prior to their adoption. Major revisions to any test procedure will be approved only after careful examination of the impact on crew preparations and familiarity. Also, only those procedural changes which are absolutely necessary for attainment of safety or test objectives or are of a "make play" nature will be approved. Pre-test briefing and training will be conducted to assure complete readiness of the flight crew, test crew, AGE, AVE and procedures. A final validation review will be conducted prior to each launch by a specially constituted and convened Flight Vehicle Technical Readiness Board.

2.2.6 Board Recommendation No. 8

Full-scale mockups in flight configuration to be tested to determine the risk of fire.

There are two basic uses of full scale mockups as tools for fire hazard testing: 1) a development test to evaluate fire detection and suppression systems and use of restricted usage materials, and 2) a qualification test of flight configured spacecrafts. MOL is still studying the value of full scale

mockups for flight vehicle qualifications. Mockups will be required in the development test stage. Since this development use is dependent on the results of the materials specification program, the exact number and type of mockup tests ultimately to be employed will be determined after further work by the Contractors.

2.2.7 Board Recommendation No. 9

A. The fire safety of the reconfigured Command Module to be established by full-scale mockup tests.

B. Studies of the use of a diluent gas to be continued with particular reference to assessing the problems of gas detection and control and the risk of additional operations that would be required in the use of a two-gas atmosphere.

The use of full-scale mockup tests is discussed in Paragraph 2.2.6.

The original Gemini B baseline atmosphere composition and cabin pressure time history were a direct carry over from NASA Gemini and were, essentially, the same as Apollo 204. Since the high oxygen level in the cabin during ground testing represented an undesirable hazard, the ground cabin atmosphere was changed to a mixed gas atmosphere. Based on results of a study by McDonnell Company, a two-gas cabin system using ground supplied oxygen and helium will be employed prior to launch, retaining the onboard 100 percent oxygen system for the suit loop. The ground based two-gas system will reduce the oxygen partial pressure to less than 5 psi during ground testing, launch, and ascent and, during all ground operations, will maintain a 3 to 1 ratio of helium to oxygen partial pressures. The crew members will be breathing a 100 percent oxygen atmosphere within the closed suit loop. This technique is acceptable from a complexity and weight standpoint and substantially reduces the pre-launch and ascent fire hazard.

Helium is fed directly into the cabin from a ground supply and is removed from the cabin through the cabin outflow valve. Oxygen is fed from a ground supply into the primary oxygen supply line and then to the suit circuit through the regulator by-pass line. After flowing through the pressure suit assembly, the oxygen enters the cabin through the pressure relief portion of the suit demand regulator and leaves the cabin through the cabin outflow valve. The oxygen is supplied to the suit loop at a high flow rate to ensure that any diluent that leaks into the loop is flushed out. Also, the suit loop pressure is maintained slightly higher than the cabin pressure.

Just prior to launch the mixed gas is trapped in the cabin by closing the cabin outflow valve. The ground supplied oxygen and helium are shut off, but oxygen from the on-board supply continues to flow through the suit circuit and into the cabin. This prevents an excessive drop in oxygen partial pressure in the cabin during ascent as the cabin total pressure is reduced through the cabin pressure relief valve and also permits the crew to continue to breathe a 100 percent oxygen atmosphere.

At orbit insertion, the cabin total pressure will be approximately 5.8 psi, with an oxygen partial pressure of 3.5 psi. At this time, flow into the suit circuit through the regulator bypass line is stopped and the suit circuit reverts to normal operation. Oxygen is added only in response to the cabin pressure regulator and the suit demand regulator to make up for crew metabolic usage and cabin leakage. During orbital flight, the suit will be vented to the cabin to prevent a concentration of helium in the suit loop; however, in the event of loss of cabin pressure the suit vent will be closed.

Figure 2-2 shows the cabin pressure during launch, ascent, and early orbit. Ultimately the cabin would approach a 100 percent oxygen atmosphere; however, the crew will transfer to the Laboratory Module before this happens. It should be noted that the criteria for materials acceptance for use in the Gemini B cabin requires qualification under the most severe atmosphere possible; e.g., with this change, 6 psi 100 percent oxygen.

The Laboratory Module baseline specifies a two-gas atmosphere; during on-orbit operations it consists of 3.5 partial pressure of oxygen and 1.5 psi partial pressure of helium. The original baseline atmosphere at launch was 15 psi total pressure consisting of 10.5 psi oxygen partial pressure and 4.5 psi helium partial pressure. Since this is a hazardous atmosphere, although no men are present, alternatives were evaluated such as 100 percent helium, clean air, or a mixture of 80 percent helium, and 20 percent oxygen. The last alternative has been selected for implementation.

The Gemini B and Laboratory atmosphere interface during orbital operations has also been reviewed. Under the original baseline, the Gemini B was repressurized with 100 percent oxygen prior to crew transfer from the Laboratory. In case of a fire emergency in the Laboratory requiring the crew to abort to the Gemini, this pure oxygen atmosphere would have made a hazardous situation worse. A capability is being added to permit repressurization of the Gemini B with a two-gas atmosphere from the Laboratory atmosphere supply source to minimize this hazard. In addition Gemini B emergency repressurization time is being sharply reduced.

2.2.8 Board Recommendation No. 10

A. An indepth review of all elements, components, and assemblies of the environmental control system to be conducted to assure its functional and structural integrity and to minimize its contribution to fire risk.

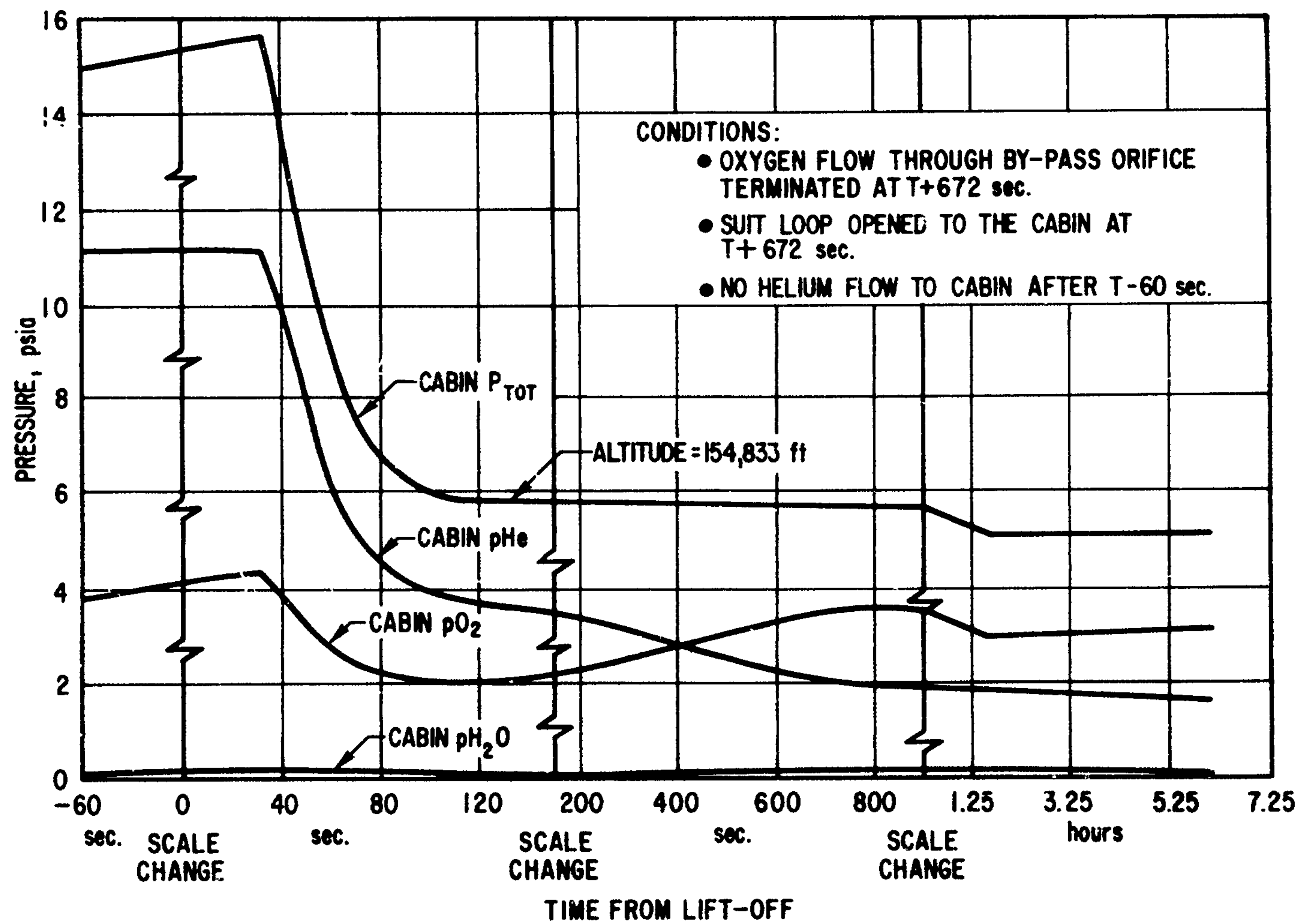


Figure 2-2. Gemini B Cabin Pressure During Launch, Ascent and Early Orbit

B. Present design of soldered joints in plumbing to be modified to increase integrity or the joints to be replaced with a more structurally reliable configuration.

C. Deleterious effects of coolant leakage and spillage to be eliminated.

The Gemini B Environmental Control System (ECS) was reviewed and found to be satisfactory with one exception. The ECS suit heat exchanger is installed inside the pressure cabin. There are both aluminum oxygen lines and coolant lines to this unit. The coolant fluid utilized is Monsanto MCS-198 with a flash point of 175°F. While there are no major ignition sources near the coolant tubes, a leak or rupture could dump this highly flammable fluid into the cabin. Other less flammable and non-flammable coolant fluids are being evaluated and will be implemented. It should be noted that the Gemini B ECS system uses either brazed or mechanical joints and not soldered joints.

The Laboratory Vehicle ECS design appears to be completely satisfactory. The coolant fluid used within the pressure cabin is water; Freon is used outside the pressurized area. The joints will all be either brazed or mechanical.

D. Review of specifications be conducted, three-dimensional jigs to be used in manufacturing wire bundles. Rigid inspection of all stages of wiring design, manufacture, and installation to be enforced.

A comprehensive review of each Associate Contractor's electrical wire harness program has been initiated. This includes both hardware design reviews and a thorough study of the Contractor specifications. Included in this specification review are the requirements and process documentation that covers design, tooling, fabrication, test, inspection, and handling. The design reviews and the specification review will be completed in

September. At that time recommendations will be prepared to correct any deficiencies in the various Contractors' wire harness programs. With reference to the Apollo Board recommendations, wiring harness will be fabricated on three dimensional forms or jigs when wire harnesses are used in three dimensional form.

E. Vibration tests to be conducted of a flight-configured spacecraft.

Vibration tests of the flight-configured Gemini B and Laboratory Vehicle are part of the baseline program. Flight 1 Gemini B will be vibration-tested to approximately 70 percent of equipment qualification level. The Laboratory Module qualification test vehicle will be structurally tested to qualification levels and to flight levels with equipment included. All flight Laboratory Vehicles will be subjected to low level acceptance vibration tests.

F. The necessity for electrical connections and disconnections with power on within the crew compartment to be eliminated.

The MOL design and preliminary crew procedures are being scrutinized for equipment items that require connection and disconnection while power is on within the pressure cabin. The crew transfer umbilical is in this category; other items may be identified as the review progresses. As items are identified, the hazard will be evaluated and, where required, alternate means of performing the operation or non-hazardous alternative designs will be implemented.

G. Investigation to be made of the most effective means of controlling and extinguishing a spacecraft fire. Auxiliary breathing oxygen and crew protection from smoke and toxic fumes to be provided.

The results of studies and tests concerned with the control and extinguishment of spacecraft fires are currently being evaluated. Because of the

unique configuration of the Orbiting Vehicle no single extinguishing agent is ideal. For example, a system using foam may be the best suppressant to use in the equipment and display consoles and panels, while water may be the best suppressant in the crew habitation area. All promising alternatives available at the present time have unattractive side effects which must be evaluated, e.g., the toxic by-product of Freon and the after effects of using water. The associate contractors having equipment within the pressurized area of the Laboratory Vehicle are being directed to conduct studies which (a) identify fuel and ignition sources, (b) consider feasible fire detection systems, (c) consider fixed and portable suppression systems and (d) study compatibility of potential suppression agents with equipment in the Laboratory Vehicle.

2.2.9 Board Recommendation No. 11

Every effort must be made to ensure the maximum clarification and understanding of the responsibilities of all organizations involved, the objective being a fully coordinated and efficient program.

The overall safety planning for MOL is being reexamined. As a result of review of the Engineering Development Phase contracts, certain inconsistencies have been identified; these are actively being corrected. An overall MOL System Safety Plan is being prepared. The purpose of this document is to do precisely what the Apollo Board recommends. The SPO has strengthened its System Safety Group which: establishes safety policies and direction; establishes, reviews and approves safety plans; and conducts program safety reviews. The Working Council of the System Safety Group will review all design and activities from the flight crew viewpoint. Plans are underway to form independent boards composed of distinguished individuals of unquestioned competence to conduct special periodic program safety assurance reviews at key points in the program. In addition, the stronger safety organization within the SPO, Aerospace Corporation, and the Associate Contractors should assure that the safety requirements are afforded adequate senior management attention.

2.3 COMPARISON OF MOL ACTIVITIES WITH CONCLUSIONS OF BROOKS AFB ACCIDENT INVESTIGATION BOARD

The Brooks AFB fire of 31 January 1967 fatally injured two airmen while they were inside a space chamber performing daily feeding, watering and cleaning chores associated with sixteen test rabbits which were in an atmosphere of pure oxygen at 7.5 psi pressure. The fire was probably ignited by a spark caused when one of the crewmen stepped on a teflon insulated electrical lamp cord which was on a metal floor. The initial fuel was probably the crewman's cotton coverall possibly even made more susceptible to ignition by clinging loose rabbit fur. There were also other flammable materials present which were determined to be unnecessarily hazardous. The investigation board's conclusions as they pertain to MOL are synopsized below. Following each conclusion is a discussion of how it applies to the MOL Program.

2.3.1 Procedures did not exclude excessively flammable solid materials from being used routinely.

The MOL spacecraft, its design, and the materials used in it are under configuration management control. The revised MOL materials selection, testing and control program provide adequate assurance that vehicle hardware will be as inflammable as is practical. It will be necessary to police the associated contiguous facility areas to provide rigorous quality control inspection over those areas as well as the flight hardware.

2.3.2 Procedures did not demand exclusion of all possible ignition sources.

The controls indicated in the preceding paragraph are also effective in reducing ignition sources. The electrical wire to be used in the MOL program has been reviewed. In addition to selection of a wire with insulation resistant to combustion, consideration has been given to the ability of the insulation to retain its anti-sparking/arcing and other insulating characteristics.

2.3.3 Training practices not sufficiently formalized to assure standardization in accomplishment of maintenance and operations.

The MOL Program is somewhat different from the Brooks AFB effort in that Brooks has many hazardous tests going on concurrently and over long periods of time whereas the hazardous MOL tests are few in number and less apt to fall into the routine category. Further the general level of complexity of space hardware has resulted in all testing being conducted using formal written procedures.

2.3.4 Inadequate time for senior scientific supervisors to participate daily in the programs.

The preceding comments are applicable in this area. MOL hazardous testing will be given senior level supervision. In general, MOL tests are not routine.

2.3.5 Ground safety program not as highly developed as could be.

MOL safety program is being strengthened. These activities are discussed in detail later in this report.

2.3.6 Emergency response of fire and medical services was extremely fast.

The superior response of the fire and medical services upon discovery of the fire demonstrated that quick reaction times are possible. The MOL Program will use this experience to establish standards knowing that they can be attained.

3. MOL SAFETY MANAGEMENT

3.1 OVERALL SAFETY MANAGEMENT

In the preceding sections, the emphasis has been on MOL activities related specifically to the fire hazard and the Apollo 204 Review Board recommendations. Of equal, and possibly more, importance are those MOL activities designed to avoid some other type of incident. The management plans and analytical activities concerned with this goal are briefly described in this section.

Concurrent with the safety assessment of the MOL hardware and MOL operational procedures following the Apollo accident, there has been a thorough review of MOL safety management. This has included review of the organizational structures of SPO/Aerospace and the Associate Contractors; the requirements and documentation areas were also examined.

3.2 MOL SYSTEM SAFETY GROUP

The SPO has a MOL System Safety Group which operates as "the principal vehicle through which the Deputy Director, MOL executes his responsibility for the overall safety management of the system". The MOL System Safety Group is divided into an Executive Council and a Working Council. The Executive Council, consisting of MOL SPO, Titan III SPO, and Aerospace Corporation members establishes safety program policy and direction. The Working Council consisting of MOL SPO, Titan III SPO, Aerospace Corporation, and Associate Contractor representatives serves as the focal point for all safety planning, analysis, and requirements definition. This Working Council maintains cognizance of the activities of the MOL Program safety working groups (e.g., Airborne Crew Safety Working Group) and safety-related activities of such other groups as the Launch Operations Planning Group, Launch Operations Working Group, Crew Transfer Working Group, etc.

The charter of the MOL System Safety Group is included as Appendix II.

The MOL SPO has established the position of Director for Safety Assurance. reporting directly to the Deputy Director, MOL. This is in addition to the System Safety Engineer. Their responsibility is the day-to-day operation of the MOL Safety Program.

The organizational structure of each Associate Contractor was reviewed and the ability of the principal safety officer to execute his responsibilities in light of his position in the chain of command was considered. The Deputy Director, MOL personally negotiated this significant aspect of safety organization with the appropriate Associate Contractor company officer.

3.3 AEROSPACE CORPORATION SAFETY COUNCIL

To ensure proper emphasis on safety in the execution of its role of Systems Engineering and Technical Direction, Aerospace Corporation established a MOL Safety Council consisting of senior representatives of the MOL Systems Engineering Office, the Electronics Division, and the Applied Mechanics Division, under the chairmanship of the Vice President and Associate General Manager of the MOL Systems Engineering Office. This Council reports directly to the company Senior Vice President, Technical. The Council's responsibility is to "assure program-wide consideration of safety objectives".

The Aerospace Corporation has established a full time Safety Office to support the Aerospace MOL Safety Council and the MOL SPO System Safety Group. Areas of activity of this office include analyses and design tradeoff studies pertaining to safety, establishment of a materials selection program from a safety standpoint, and review and analysis of testing and manufacturing procedures.

3.4 LAUNCH SITE SAFETY MANAGEMENT

It is the responsibility of the 6595th Aerospace Testing Wing (ATW) and the Air Force Western Test Range (AFWTR) to assure that all reasonable precautions are taken to minimize the risks of life, health, and property at the launch site.

The Office of Prime Responsibility for the implementation and management of MOL ground safety at VAFB in the Engineering and Safety Branch of the Manned Programs Division, 6595th Aerospace Test Wing. It has the responsibility for approving safety documentation, reviewing test operations and data, determining the adequacy of corrective action, reviewing engineering changes and establishing strict disciplines to be followed in all operations affecting safety.

3.5 SAFETY SURVEILLANCE PROGRAM

All space programs have thorough engineering review, manufacturing monitoring, and quality control programs and their effectiveness is related directly to top level management interest and involvement. The MOL Program has planned the normal hardware design reviews, configuration management, quality assurance, and similar activities. In addition, significant management participation of all contractors is being required in a series of formally scheduled activities.

3.5.1 Flight Vehicle Technical Readiness Program

The Air Force/Aerospace experience on the Mercury and Gemini booster programs shows that a program of constant vigilance over hardware from manufacturing through acceptance and launch operations culminates in successful flights. As in Mercury and Gemini, product integrity will be assured through rigid acceptance and technical review disciplines, supported strongly by top level contractor and program management personnel.

This is accomplished through the establishment of time-oriented controls over program activities at each segment factory and at VAFB, coupled with a set of supporting controls and requirements in the areas of test analysis adequacy and integrity, failure analysis and corrective action, effective application of data trend concepts, spares, reliability, critical component controls, procedures, and personnel motivation.

3.5.1.1 Contractor Flight Readiness Validation Boards

Each Associate Contractor and the Aerospace Corporation will convene special Flight Readiness Validation Boards, headed by a senior official at a level not less than Division, Company or Corporation President to evaluate readiness for flight, with emphasis on safety. Chairmen of these Boards will report to the Deputy Director, MOL, at the Flight Vehicle Technical Readiness Board prior to each flight.

3.5.1.2 Flight Vehicle Technical Readiness Board

As a part of the final activities before launch, a complete summary of significant items including test history, problems and resolutions, impacts and analyses of failures in allied or related programs, and overall mission preparedness of the MOL system will be prepared. This summary will be presented to the Flight Vehicle Technical Readiness Board chaired by the Deputy Director, MOL, immediately prior to launch.

The purpose of the board will be to assure that the MOL system is in a satisfactory state of readiness and to commit the Flight Vehicle to launch.

3.5.2 Independent Program Safety Surveillance

Critical reviews of the MOL Program by qualified personnel not directly related with the program will further assist the Deputy Director, MOL, in meeting his responsibilities. In addition to Boards mentioned above, which are internal to the MOL Program, two independent boards are being established.

3.5.2.1 MOL Program Safety Assurance Board

As a means of ensuring that external visibility is given to all aspects of safety, plans are being formulated to organize a MOL Program Safety Assurance Board, consisting of distinguished individuals not associated with MOL, to conduct exhaustive periodic reviews. These reviews will provide an independent assessment of the health of MOL Safety from a program-wide standpoint.

3.5.2.2 MOL Flight Safety Certification Board

Prior to the beginning of preparations for each significantly different vehicle configuration, a MOL Flight Safety Certification Board, consisting of prominent, skilled individuals not directly associated with the MOL Program, will be convened to conduct a detailed examination of all aspects of the pending flight with respect to safety. Their examinations will provide an independent certification of flight safety readiness.

4. SUMMARY AND CONCLUSIONS

The Apollo 204 Review Board findings and recommendations have been compared in Section 2 to the MOL baseline design and plans and to the MOL activities initiated as a result of the Apollo fire. Further activities of the MOL Program related to the conclusions of the Brooks Air Force Base Investigation Board have been discussed.

In general, the MOL Program baseline incorporates the elements required for safety. This includes certain design features such as the Laboratory Vehicle two-gas atmosphere, the Gemini egress capability, and the basic Gemini design of having the bulk of the electronic components outside the pressure cabin. However, the accelerated review resulting from the Apollo accident has identified some areas for further improvement. These include instituting a stricter materials program, changing the Gemini atmosphere at launch to include a diluent gas, and adding fire detection and suppression equipment to the Laboratory Vehicle. These improvements will have both a cost and weight impact on the MOL Program.

It is believed that the safety procedures, plans, analyses, and study activities that are a basic part of the MOL Program will result in the identification of other potential hazards in sufficient time to take corrective action and prevent their occurrence. This is particularily true since the stronger safety organizational structure should assure proper management level review of these areas as they are identified.

5. REFERENCES

1. MIL-S-38130A, "System Safety Engineering of Systems and Associated Subsystems and Equipment; General Specification For", dated 6 June 1966.

2. NASA Specification ASPO-RQTD-D67-5A, "Nonmetallic Materials Selection Guidelines", dated 3 May 1967.

3. MAC Report F315, "Gemini B Oxygen Safety Study", dated 15 May 1967.

4. Report of Apollo 204 Review Board to Administrator National Aeronautics and Space Administration, dated 5 April 1967.

5. SS-MOL-1A, "System Performance/Design Requirements General Specification for the Manned Orbiting Laboratory Program", dated 1 September 1966.

APPENDIX I

APOLLO 204 BOARD FINDINGS, DETERMINATIONS AND RECOMMENDATIONS

In this Review, the Board adhered to the principle that reliability of the Command Module and the entire system involved in its operation is a requirement common to both safety and mission success. Once the Command Module has left the earth's environment the occupants are totally dependent upon it for their safety. It follows that protection from fire as a hazard involves much more than quick egress. The latter has merit only during test periods on earth when the Command Module is being readied for its mission.and not during the mission itself. The risk of fire must be faced; however, that risk is only one factor pertaining to the reliability of the Command Module that must receive adequate consideration. Design features and operating procedures that are intended to reduce the fire risk must not introduce other serious risks to mission success and safety.

1. FINDING:

a. There was a momentary power failure at 23:30:55 GMT.

b. Evidence of several arcs was found in the post fire investigation.

c. No single ignition source of the fire was conclusively identified.

DETERMINATION:

The most probable initiator was an electrical arc in the sector between the -Y and +Z spacecraft axes. The exact location best fitting the total available information is near the floor in the lower forward section of the left-hand equipment bay where Environmental Control System (ECS) instrumentation power wiring leads into the area between the Environmental Control Unit (ECU) and the oxygen panel. No evidence was discovered that suggested sabotage.

2. FINDING:

a. The Command Module contained many types and classes of combustible material in areas contiguous to possible ignition sources.

b. The test was conducted with a 16.7 pounds per square inch absolute, 100 percent oxygen atmosphere.

DETERMINATION:

The test conditions were extremely hazardous.

RECOMMENDATION:

The amount and location of combustible materials in the Command Module must be severely restricted and controlled.

3. FINDING:

a. The rapid spread of fire caused an increase in pressure and temperature which resulted in rupture of the Command Module and creation of a toxic atmosphere. Death of the crew was from asphyxia due to inhalation of toxic gases due to fire. A contributory cause of death was thermal burns.

b. Non-uniform distribution of carboxyhemoglobin was found by autopsy.

DETERMINATION:

Autopsy data leads to the medical opinion that unconsciousness occurred rapidly and that death followed soon thereafter.

4. FINDING:

Due to internal pressure, the Command Module inner hatch could not be opened prior to rupture of the Command Module.

DETERMINATION:

The crew was never capable of effecting emergency egress because of the pressurization before rupture and their loss of consciousness soon after rupture.

RECOMMENDATION:

The time required for egress of the crew be reduced and the operations necessary for egress be simplified.

5. FINDING:

Those organizations responsible for the planning, conduct and safety of this test failed to identify it as being hazardous. Contingency preparations to permit escape or rescue of the crew from an internal Command Module fire were not made.

a. No procedures for this type of emergency had been established either for the crew or for the spacecraft pad work team.

b. The emergency equipment located in the White Room and on the spacecraft work levels was not designed for the smoke condition resulting from a fire of this nature.

c. Emergency fire, rescue and medical teams were not in attendance.

d. Both the spacecraft work levels and the umbilical tower access arm contain features such as steps, sliding doors and sharp turns in the egress paths which hinder emergency operations.

DETERMINATION:

Adequate safety precautions were neither established nor observed for this test.

RECOMMENDATIONS:

a. Management continually monitor the safety of all test operations and assure the adequacy of emergency procedures.

b. All emergency equipment (breathing apparatus, protective clothing, deluge systems, access arm, etc.) be reviewed for adequacy.

c. Personnel training and practice for emergency procedures be given on a regular basis and reviewed prior to the conduct of a hazardous operation.

d. Serivice structures and umbilical towers be modified to facilitate emergency operations.

6. FINDING:

Frequent interruptions and failures had been experienced in the overall communication system during the operations preceding the accident.

DETERMINATION:

The overall communication system was unsatisfactory.

RECOMMENDATIONS:

a. The Ground Communication System be improved to assure reliable communications between all test elements as soon as possible and before the next manned flight.

b. A detailed design review be conducted on the entire spacecraft communication system.

7. FINDING:

a. Revisions to the Operational Checkout Procedure for the test were issued at 5:30 pm EST January 26, 1967 (209 pages) and 10:00 am EST January 27, 1967 (4 pages).

b. Differences existed between the Ground Test Procedures and the In-Flight Check Lists.

DETERMINATION:

Neither the revision nor the differences contributed to the accident. The late issuance of the revision, however, prevented test personnel from becoming adequately familiar with the test procedure prior to its use.

RECOMMENDATIONS:

a. Test Procedures and Pilot's Checklists that represent the actual Command Module configuration be published in final form and reviewed early enough to permit adequate preparation and participation of all test organization.

b. Timely distribution of test procedures and major changes be made a constraint to the beginning of any test.

8. FINDING:

The fire in Command Module 012 was subsequently simulated closely by a test fire in a full-scale mock-up.

DETERMINATION:

Full-scale mock-up fire tests can be used to give a realistic appraisal of fire risks in flight-configured spacecraft.

RECOMMENDATION:

Full-scale mock-ups in flight configuration be tested to determine the risk of fire.

9. FINDING:

The Command Module Environmental Control System design provides a pure oxygen atmosphere.

DETERMINATION:

This atmosphere presents severe fire hazards if the amount and location of combustibles in the Command Module are not restricted and controlled.

RECOMMENDATIONS:

a. The fire safety of the reconfigured Command Module be established by full-scale mock-up tests.

b. Studies of the use of a diluent gas be continued with particular reference to assessing the problems of gas detection and control and the risk of additional operations that would be required in the use of a two gas atmosphere.

10. FINDING:

Deficiencies existed in Command Module design, workmanship and quality control, such as:

a. Components of the Environmental Control System installed in Command Module 012 had a history of many removals and of technical

difficulties including regulator failures, line failures and Environmental Control Unit failures. The design and installation features of the Environmental Control Unit makes removal or repair difficult.

b. Coolant leakage at solder joints has been a chronic problem.

c. The coolant is both corrosive and combustible.

d. Deficiencies in design, manufacture, installation, rework and quality control existed in the electrical wiring.

e. No vibration test was made of a complete flight-configured spacecraft.

f. Spacecraft design and operating procedures currently require the disconnecting of electrical connections while powered.

g. No design features for fire protection were incorporated.

DETERMINATION:

These deficiencies created an unnecessarily hazardous condition and their continuation would imperil any future Apollo operations.

RECOMMENDATIONS:

a. An in-depth review of all elements, components and assemblies of the Environmental Control System be conducted to assure its functional and structural integrity and to minimize its contribution to fire risk.

b. Present design of soldered joints in plumbing be modified to increase integrity or the joints be replaced with a more structurally reliable configuration.

c. Deleterious effects of coolant leakage and spillage be eliminated.

d. Review of specifications be conducted, 3-dimensional jigs be used in manufacture of wire bundles and rigid inspection at all stages of wiring design, manufacture and installation be enforced.

e. Vibration tests be conducted of a flight-configured spacecraft.

f. The necessity for electrical connections or disconnections with power on within the crew compartment be eliminated.

g. Investigation be made of the most effective means of controlling and extinguishing a spacecraft fire. Auxiliary breathing oxygen and crew protection from smoke and toxic fumes be provided.

11. FINDING:

An examination of operating practices showed the following examples of problem areas:

a. The number of the open items at the time of shipment of the Command Module 012 was not known. There were 113 significant Engineering Orders not accomplished at the time Command Module 012 was delivered to NASA; 623 Engineering Orders were released subsequent to delivery. Of these, 22 were recent releases which were not recorded in configuration records at the time of the accident.

b. Established requirements were not followed with regard to the pre-test constraints list. The list was not completed and signed by designated contractor and NASA personnel prior to the test, even though oral agreement to proceed was reached.

c. Formulation of and changes to pre-launch test requirements for the Apollo spacecraft program were unresponsive to changing conditions.

d. Non-certified equipment items were installed in the Command Module at time of test.

e. Discrepancies existed between NAA and NASA MSC specifications regarding inclusion and positioning of flammable materials.

f. The test specification was released in August 1966 and was not updated to include accumulated changes from release date to date of the test.

DETERMINATION:

Problems of program management and relationships between Centers and with the contractor have led in some cases to insufficient response to changing program requirements.

RECOMMENDATION:

Every effort must be made to insure the maximum clarification and understanding of the responsibilities of all the organizations involved, the objective being a fully coordinated and efficient program.

APPENDIX II

MOL SYSTEM SAFETY GROUP

CHARTER

1. PURPOSE

The MOL System Safety Group provides a forum for the mutual discussion, identification and definition of system-wide safety problems, determination of solutions and development of agreed and coordinated courses of action through which these solutions can be put into effect.

2. AUTHORITY

The MOL System Safety Group is organized under the authority of AFR 127-1 and will be the principal vehicle through which the Deputy Director, MOL executes his responsibility for the overall safety management of the system.

3. OBJECTIVE

The objective of the safety group is to achieve maximum system/crew safety throughout the design, development, testing, handling, and use of the Manned Orbiting Laboratory System, support equipment, and facilities, consistent with assigned mission responsibilities.

4. SCOPE

Under the authority delegated by the Secretary of the Air Force to the Deputy Director, MOL/Deputy Commander, SSD for MOL for implementation of the MOL Program, the provisions of this Charter apply to all aspects of and participants in the Manned Orbiting Laboratory (MOL) Program/Program 632A, including contractors and supporting government activities.

5. ORGANIZATION

The MOL System Safety Group is comprised of (1) an Executive Council,

and (2) a Working Council. Membership of each council is as follows:

a. Executive Council

Chairman - Assistant Deputy Director, MOL.

Secretariat - Safety Engineer, Directorate of Engineering.

Members - Director of Engineering, Director of Test Operations, Director for Bioastronautics, Director for Safety Assurance, Titan III System Program Director, and Chairman, Aerospace Corporation Safety Council.

The Vice Director, MOL, may designate a member of his staff, at his discretion, to observe the deliberations of the Executive Council.

b. Working Council

Chairman - Safety Engineer*, Directorate of Engineering.

Secretariat - Aerospace Corporation Safety Office Director.

Members - Specific designees from: Engineering Directorate, Test Operations Directorate, Bioastronautics Directorate, Navy MOL, 6595th Aerospace Test Wing, Headquarters USAF Directorate of Aerospace Safety (AFIAS), Titan III SPO, Martin Marietta Company, McDonnell Douglas Company (St. Louis and Huntington Beach), General Electric Company, and Pressure Suit Agency.

The Chairman of the Working Council, with the concurrence of the Executive Council, may make changes in Working Council membership as may be appropriate from time to time. He shall publish and maintain current a list of the names of the individuals constituting the Working Council.

6. RESPONSIBILITIES

a. The Executive Council shall:

*Secretariat, Executive Council

(1) Generate safety program policy and direction.

(2) Recommend to the Deputy Director, MOL, appropriate courses of action, as required, on safety matters which impact design, costs, schedules, or personnel safety.

b. The Working Council shall:

(1) Conduct its activities under the general guidance and direction of the Executive Council.

(2) Maintain cognizance of the activities of all MOL Program Safety Working Groups.

(3) Identify, review, and define safety requirements in conjunction with, or in addition to, those defined by the responsible contractors and/or government agencies.

(4) Assure that timely safety analyses and studies are conducted in all major system and subsystem areas to generate necessary safety standards and/or measurement of hazards for management decisions, and program direction.

(5) Assure that safety activities involving all program elements are scheduled to meet major program milestones.

(6) Provide for planning to insure accomplishment of safety research if required.

(7) Review safety design criteria and provide recommendations to the appropriate MOL Systems Office(s).

(8) Provide for continuous surveillance of practices and conditions to insure compliance with safety criteria.

(9) Assure that operational and training safety requirements are

incorporated into all appropriate program elements.

(10) Assure that safety evaluation of technical design and system integration of information in support of the preparation of safety documents, reports, procedures, checklists, manuals, and training requirements are conducted.

(11) Provide for technical support and participate in accident/ incident investigations.

(12) Recommend to the responsible OPR and the Configuration Control Board appropriate safety priority requirements for configuration changes.

(13) Prepare, or have prepared, reports as necessary specifying all identified safety hazards, for distribution to associate and facility contractors. These reports will be reviewed and analyzed by each contractor for any effect on systems for which they have responsibility.

7. OPERATION

a. System Safety Group

The Executive Council exercises overall guidance and direction within the MOL System Safety Group and utilizes the Working Council as its agent for the day-to-day identification and resolution of system safety problems. Those problems which cannot be resolved by the Working Council will be referred to the Executive Council.

b. Executive Council

(1) Meetings will be convened at the direction of the Chairman, normally with not less than 5 working days' notice. Where urgency demands, meetings may be called on shorter notice at the discretion of the Chairman.

(2) Scheduling of meeting dates and establishment of agenda items will be accomplished and published by the Secretariat, in coordination with the Chairman, and distributed to Executive Council members normally 48 hours in advance of meetings.

(3) Minutes will be developed at each meeting and forwarded to each member within one week. Upon approval by the Chairman, a copy will be transmitted to the Deputy Director, MOL.

c. Working Council

(1) Meetings will be convened at the direction of the Chairman, normally with not less than 5 working days' notice. Where urgency demands, meetings may be called on shorter notice at the discretion of the Chairman.

(2) Other attendees, in addition to regular Working Council members, may be present and enter the deliberations of the Working Council, at the discretion of the Chairman, to provide for technical support and related purposes as may be necessary. However, the responsibility of regular members cannot be delegated to these supporting attendees.

(3) The Chairman is responsible for restricting attendance to those essential to the conduct of Working Council business, and will limit attendance at special meetings involving only a portion of the group membership.

(4) Scheduling of meeting dates and establishment of agenda items will be accomplished and published by the Chairman. Where possible, a tentative agenda will be forwarded to each representative at least one week in advance of scheduled meetings. When deemed appropriate, meetings with MOL Safety Working Groups may be jointly scheduled.

(5) Minutes will be developed at each meeting and forwarded to each member within one week. Upon approval by the Chairman, a copy will be furnished the Deputy Director, MOL, and each member of the Executive Council.

(6) The Chairman will maintain the official files for all activities of all elements of the System Safety Group.